A report is presented of a study to determine how many people die of unintentional carbon monoxide poisoning in cars and to develop proposals for countermeasures. Results are reported and discussed; countermeasures are suggested.

Fatal Unintentional Carbon Monoxide Poisoning in Motor Vehicles

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Introduction

The potential health hazard created by sublethal concentrations of carbon monoxide from automotive exhaust in the atmosphere has evoked increasing concern.[1,2] At the same time, the large number of deaths that occur in vehicles when lethal concentrations of carbon monoxide enter the passenger compartment has escaped widespread attention. This paper presents data suggesting that over 500 Americans die each year from carbon monoxide poisoning because their vehicles are defective due to deterioration, damage, or poor automotive design.

Most of these deaths occur in non-moving vehicles; therefore they are not classified as "motor vehicle accidents" and rarely are thought of in connection with vehicular deaths. Yet probably no other group of deaths is more closely related to defective motor vehicles.

In 1967, 819 deaths in the U.S. were classified as "accidental poisoning by motor vehicle exhaust gas."[3] As with many types of adult poisoning, information on these deaths is scanty because they rarely reach the hospital alive and therefore are not reported through the poison control information system.

Sopher and Masemore's report on 6 recent carbon monoxide deaths described methods of investigation and disclosed the role played by defective vehicles.[4] Their findings led to this review of all Maryland deaths during the past six years caused by unintentional carbon monoxide poisoning in motor vehicles. The objectives were to document the size of the problem, describe the age and condition of the vehicles and the circumstances under which these deaths occurred, and consider the possible solutions suggested by the data.

Method and Materials

Records at the Office of the Chief Medical Examiner of Maryland were reviewed for all deaths attributed to asphyxia from carbon monoxide during the years 1966 through 1971. Cases were selected for inclusion in the study if CO poisoning occurred inside a vehicle and there was no indication that death was deliberate.

Information noted for each case included date and county of death; age, race, sex, blood alcohol concentration and carboxyhemoglobin (COHb) saturation; circumstances under which death occurred; and any available information on vehicle age, make, and pertinent defects. Detailed information relating to the vehicles was available for 11 vehicles investigated by one of the authors (WCM) during the last two years of the study and for 12 additional vehicles investigated by police agencies.

Postmortem examinations had been performed at the Office of the Chief Medical Examiner (OCME) in Baltimore, or by deputy medical examiners in other parts of the state. All toxicological analyses had been done at the OCME. Carbon monoxide hemoglobin saturation of the blood was determined by the Freimuth-Gettler method.[5]

Results

Sixty-eight deaths met the criteria for inclusion in the study. Fifty-four vehicles were involved, including 4 trucks. There were 12 cars in which two persons died, and one in which three died. In 6 cases, one or more additional persons had been in the car but survived exposure to carbon monoxide.

In 5 (14%) of the 35 cases where persons were alone in their vehicles, carbon monoxide poisoning was not suspected until routine chemical analysis of the blood revealed high levels of carboxyhemoglobin. Four of these drivers, ages 49 to 70, were initially thought to have died of natural causes. The fifth, age 38, was found face down on the car seat and his death was at first attributed to mechanical asphyxia.

Table 1 shows the age distribution of the persons who died; the median age was 30; Forty-three (63%) were males.

Table 1—Age of Persons Who Died

Age	Number
14-19	9
20-29	24
30-39	16
40-49	10
50-59	4
60-69	3
70+	2
Total	68

Carboxyhemoglobin (CoHb) findings are shown on Table 2. Severe arteriosclerotic coronary artery disease (which diminishes myocardial blood flow and oxygenation) was noted in the person who died with a COHb saturation of 30% and in one who died at 40%. Alcohol intoxication of 4 of the 5 persons with COHb in the 40-49% range may have contributed to death at COHb saturations that are not usually lethal.

Only 2 deaths occurred after arrival at a hospital. Both of these persons survived for a day or longer but never regained consciousness. A third case of delayed death involved a person who lost consciousness from CO poisoning while parked with the motor running, but lived long enough after the car ran out of gas for the blood CO to be eliminated. (Her companion awoke 34 hours after they had parked, disoriented and suffering from frostbite.)

Table 2—Per cent Carbon Monoxide Hemoglobin Saturation

COHb Saturation, %	Number
30-39	1
40-49	5
50-59	10
60-69	43
70-79	6
Total	65*

* Excludes 3 cases in which survival following poisoning was sufficiently prolonged for blood CO to be eliminated.

Table 3—Month of Occurrence

Month	Number of cases	Number of deaths
January	10	12
February	6	6
March	1	1
April	3	3
May	4	5
June	2	2
July	0	0
August	1	1
September	3	4
October	4	6
November	7	9
December	13	19
Total	54	68

Usually it appeared that the engine had been left running so the heater could warm the car. Table 3 shows the distribution of cases by month of death. Forty-six deaths (68%) occurred during the four-month period, November through February. Almost all the deaths occurred at night; except during the summer, nighttime temperatures in Maryland are often low enough to warrant use of a heater.

Three-fourths of the deaths involved men sleeping in cars or couples parked in cars, under circumstances that reflect the wide variety of uses to which automobiles are put. Many of the men had been in the habit of sleeping in their cars after they had been drinking. Back trouble led one man to sleep in his station wagon. A married couple died at a drive-in movie; a young unmarried couple was sitting in a car in the girl's driveway; many couples were parked in remote areas suited to romantic activities.

Table 4 summarizes the circumstances under which these deaths occurred and shows the distribution of blood alcohol concentrations. Thirty-three of the 66 who were tested had been drinking; their blood alcohol concentrations ranged from 0.04% to 0.30% by weight, with a median of 0.10%. In general, the highest alcohol concentrations were found in persons who had been sleeping in cars. Although in many cases involving alcohol it was known that the person planned to sleep in the car, no doubt there were some instances in which sleep was not intended but was induced by the combination of alcohol and carbon monoxide.

Three vehicles were in motion when the driver was overcome by CO: one car ran off the road into the woods, another blocked an intersection, and a delivery truck came to rest on a grassy median. At least two other cars may have been in motion immediately prior to the driver's death, but no incident caused a collision with another car.

Persons who died in older cars were more likely to have been drinking than those in newer cars. Eleven out of 14 persons in cars over 8 years old had been drinking, compared to 11 out of 27 persons in cars that were 8 model years or less.

Fifteen of the vehicles had been parked inside garages or service stations with the engine running, apparently to provide heat. In these cases, the age or condition of the vehicle was not considered pertinent to this study, since even with the garage doors open—as was true in several

Table 4—Circumstances of Event and Blood Alcohol Concentration

Circumstances	Alcohol (% by wt.) .00	.01-.09	0.10+	Unk.	Total
Sleeping	6	3	11	0	20
Couples parking	17	8	3	2	30
Driving	3	0	0	0	3
Stuck in snow or mud	0	2	1	0	3
Working on car	1	1	1	0	3
Warming car or charging battery	2	0	0	0	2
Other	4	1	2	0	7
Total	33	15	18	2	68

Table 5—Age of Vehicles

Age (years)	Vehicles in study		Registered vehicles*
	#	%	%
0-1	3	9	22
2-3	4	12	23
4-5	5	15	22
6-7	5	15	15
8-9	9	28	9
10+	7	21	9
Total age known	33	100	100
Age unknown	6		
Total†	39		

* From registration figures compiled by R.L. Polk and Co., for all vehicles in operation in Maryland as of July 1, 1970.

† Excludes 15 vehicles parked inside.

cases in which a car was backed into a garage—it would be possible for fatal concentrations of CO to accumulate in the absence of defective exhaust systems.

The other 39 vehicles were outdoors. Their condition was considered pertinent to the 51 deaths that resulted.* Table 5 shows the age distribution of these vehicles. (Although vehicle age was not reported in 6 cases, there is no indication that this introduced a bias. The median age of cars whose age was included in the original case file was similar to cars whose ages were initially unreported but subsequently obtained from additional sources.) In general, the vehicles were significantly older than the population of all cars registered in Maryland during 1970: the median age was 7.6 years compared to 4.4 for the population of registered cars ($p<.01$).

The exhaust systems of 23 of the 39 vehicles were examined. Defects such as holes in the muffler and broken tailpipes were found in 21. Poor design was noted in the case of a late-model sedan in which the tailpipe was too short to extend outside the rear fender; upward displacement of the tailpipe by an earlier impact had resulted in exhaust gases striking and corroding the inner fender panel. The only car in which the entire exhaust system appeared to be in good order had a gravel-shield under the rear bumper which deflected exhaust fumes forward toward a large rusted-out area in the rear fender.

Reports for 7 of the 23 vehicles that were examined did not mention any attempt to determine how the exhaust fumes had entered the passenger compartment. In the remaining 16 cases a point of entry was sought and found. Usually fumes entered through holes in the floor of the passenger compartment, fender panels, or trunk (from which fumes can easily enter the passenger compartment of most cars). In two instances, fumes apparently entered through holes in the trunk or spare tire well that were originally plugged with rubber at the time of manufacture.

Rust was a major factor in most cases, having caused a combination of exhaust-system defects plus holes in the body. Even 2-year-old cars had significant rust damage (no cars less than 2 years old had been examined). In addition to rust damage, mechanical damage to components of the exhaust system or to the body was involved in several cases.

* Make and year of these vehicles will be furnished by the author on request.

Seven cars had at least 1 window open for a distance of ½″ to 4″, which many people may think is an adequate precaution against CO poisoning. Two of these cars were subjected to carbon monoxide tests while parked with the engine running, and accumulated potentially fatal CO concentrations with the window in the same position as when the bodies were discovered. One of them, with the window open ½″, built up a 0.1% CO level in 30 minutes. This level produces a fatal carboxyhemoglobin saturation in the blood in 3-4 hours.[6] The other tested car had a window open about 4″, and exhaust fumes may actually have entered through this window as well as through the trunk.

Several other cars were found with one or more windows completely open; in one case a window apparently was opened by an occupant before he died, in other cases windows may have been opened by someone who discovered the body.

Discussion

The deaths in this study can be divided into two main groups: 27 occurring in vehicles that were indoors and 51 in vehicles out of doors. The latter group is considered to be related to faulty vehicles, partly because lethal concentrations of CO could not otherwise be explained and partly because abnormalities were found in each vehicle that was examined.

In addition to the 68 persons who died in their vehicles, 3 Marylanders died from exhaust fumes when they were not in their cars,* making a total of 71 deaths due to "accidental poisoning by motor vehicle exhaust gas." The 51 deaths that were related to the condition of the vehicle comprise 72% of this total group. If the same percentage prevails nationally, then approximately 590 deaths† occur annually in the U.S. as the result of faulty vehicles.

Considering the power of human needs for sleep, sex, and warmth, and the ready availability of automobiles which can provide not only heat but also privacy for the first two needs, perhaps the remarkable thing is that these deaths are not even more numerous. Certainly the problem is widespread.[7] Approaches that depend upon modifying human behavior probably have little chance of solving the problem, in part because so many of the cases involve alcohol, which can decrease awareness of the danger and add to the tendency to fall asleep. When persons with cars in poor condition are also heavy drinkers—as suggested by the association noted between older vehicles and high blood alcohol levels—the risk of CO poisoning is compounded.

There is also evidence of a synergistic effect of alcohol and carbon monoxide, leading to death at lower COHb saturation levels when the blood alcohol concentration is high.[8] Furthermore, the marked association between heavy drinking and heavy smoking noted by Waller and Thomas[9] suggests that many intoxicated persons in the present study may have been smoking heavily, thus causing additional COHb elevation.

* Two died in their homes when automobiles were left idling in basement garages. The third was pinned between rear bumper and garage door when she walked behind a car that was "warming up."

† Based upon U.S. figures of 819 accidental deaths in 1967 from exhaust fumes. Underreporting, resulting from classifying unrecognized carbon monoxide deaths as "natural," may be balanced by the classification of some questionable suicides as "accidents."

A wealth of promising approaches to the prevention of carbon monoxide deaths from motor vehicle exhaust is suggested by consideration of Haddon's strategies for reducing losses due to harmful interactions between man and his environment.[10] Combinations of some of the following countermeasures could substantially reduce the number of these deaths.

Some approaches involve modifying vehicles before they reach the consumer. Completely eliminating the production of CO—with a different type of engine or a fuel that does not produce carbon monoxide—would eliminate not only these inadvertent deaths but also CO suicides in cars and the problems associated with atmospheric pollution by CO.

Reducing the concentration of CO in exhaust gases, now possible with exhaust emission control devices, would decrease the likelihood that lethal concentrations of CO would build up inside cars. It is of interest that one death in this series occurred in a car that had been so equipped—but the device had been disconnected to provide additional horsepower!

Better separation of exhaust fumes from the passenger compartments could be achieved in several ways. For instance, exhaust fumes might be released in a different place or in an altered direction so they would be carried away from the body of the car. Also, establishing an airtight seal between trunk and passenger compartment would prevent many deaths that occur when fumes follow this route. Mechanical damage to the exhaust system might be reduced by locating components so they are less subject to impact. Rusting-out of the exhaust system and body could be prevented by making the relevant structures from less corrodible materials or from heavier-gauge metal. Additional benefits would result if manufacturers were to assume the responsibility for coating these components with rust inhibitors.

Beginning with 1971 models, some automobiles have a fan-operated ventilation system that circulates fresh air through the passenger compartment and produces a slightly positive pressure designed to keep out exhaust fumes. However, such a system might not be adequate in cases where rusted-out areas are extremely large.

A built-in warning sensor that could detect carbon monoxide fumes in the passenger compartment would be useful if it gave a warning that could not be ignored by the occupants. "This approach however, requires an inexpensive, reliable sensor, which is not presently available."[11]

Modification of new cars is essential, but cannot solve the problem quickly, since the median lifespan of an American car is 10 years.* Therefore, countermeasures that can affect vehicles presently on the road are also needed. For example, rusting would be reduced if a less corrosive substitute were found for road salt.

The problem created by these hazardous defects in vehicles must be publicized so that owners and mechanics will recognize potentially lethal situations and correct them. Although some defects might not be noticed by owners, many vehicles in this series showed evidence of poor maintenance, with failure to repair obvious damage caused by rust and impacts. Seven case histories indicated that the owners knew their exhaust systems were defective; apparently many people need to be protected by measures that don't depend upon human discretion.

Effective periodic motor vehicle inspection (PMVI) might be expected to help, but of the 32 states that have periodic inspections, only 16 check for floor pan holes that would permit fumes to enter a car, and none requires inspection for holes in the fender panels. Two states with PMVI do not even require a check for defective exhaust pipes or mufflers.[12] Maryland does not have PMVI, but the effectiveness of current inspection procedures in other states may be questioned since three vehicles in this study were registered in states that include the exhaust system in their yearly or twice-yearly inspection. One of the 3 had been "inspected" only a week before obvious and long-standing rust damage caused a death in a neighboring state.

This car was of particular interest because a month later another person died while sleeping in it, in Maryland. There is need for an established procedure to ensure that a car in which someone has been poisoned by carbon monoxide will be impounded until the problem is corrected. Unfortunately, police may close these cases without taking steps to protect future users of a car. It is a matter of concern that many police reports—even those that were otherwise very detailed—made no mention of inspecting the vehicle to determine how poisoning had occurred, or of warning the owners of the hazards involved in using the car.

A history of headache, vertigo, or nausea associated with driving should alert physicians to the possibility of CO poisoning. Three persons in the study had experienced such symptoms on several occasions before the fatal event, but the cause was not suspected. CO poisoning should be considered whenever someone collapses in a car; that it was initially unsuspected in 14% of all cases where the deceased was alone, demonstrates the importance of testing for COHb whenever anyone dies in a car.

Immediate administration of oxygen, which accelerates elimination of CO from the body, is indicated when CO poisoning is suspected and the victim is still alive.[6] Subsequent therapy with hyperbaric oxygen can often prevent both death and the neuropsychiatric sequelae of severe CO poisoning.[13,15] A mobile pressure chamber has been used for hyperbaric oxygen therapy, with excellent results; because it can be transported by ambulance or helicopter it eliminates the necessity of transferring a patient.[16]

A study in England found that less than half the cases of CO poisoning that reached the hospital alive were given oxygen.[17] In the present study, the 2 persons who died in the hospital received oxygen, but not hyperbaric oxygen therapy.

The present investigation raises the question of the possible role of sublethal doses of carbon monoxide in motor vehicle crashes. Occasional crashes have resulted from exhaust fumes in the passenger compartment, but investigations of large series of fatally injured drivers indicate that COHb levels greater than those associated with smoking are uncommon.[9,18,19] However, the growing popularity of air-conditioned cars can be expected not only to make death in closed cars a year-round phenomenon instead of one primarily associated with cool weather, but also to increase the likelihood of CO poisoning in moving vehicles.

Although the number of deaths caused by CO-in-

* Calculated by Richard S. Eiswirth, Insurance Institute for Highway Safety, from tables in *Automotive News Almanac.*

duced crashes is probably smaller than the number caused by CO in the absence of crashes, both types of death point to the need to modify future vehicles so that deadly carbon monoxide fumes will not enter the passenger compartment. In addition to preventing fatal accumulation of carbon monoxide in moving vehicles, vehicle design must take into account the fact that an engine may run for a long period of time while the vehicle is parked.

Summary

An investigation was undertaken to determine how many persons die in motor vehicles as the result of unintentional carbon monoxide poisoning, and to develop suggestions for potentially effective countermeasures. Sixty-eight such deaths were found to have occurred in Maryland during 1966-71. Fifty-one of the deaths were associated with faulty vehicles, usually due to rust. As a group these vehicles were significantly older than the population of registered vehicles. Three vehicles came from states with periodic vehicle inspection. Most deaths involved stationary vehicles, with the engine running to provide warmth. Three drivers were overcome by fumes while their cars were in motion. CO poisoning was not suspected initially in 14% of cases where the deceased was alone in the car. Suggested countermeasures include modifications to future cars, detection and correction of defects in existing vehicles, and prompt oxygen therapy for victims who are found alive.

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References

1. Goldsmith, J.R. Carbon monoxide. Science 157:842-4, 1967.
2. Hexter, A.C. and Goldsmith, J.R. Carbon monoxide: Association of community air pollution with mortality. Science 172:265-266, 1971.
3. National Center for Health Statistics: Vital Statistics of the United States, 1967, Vol II, Part A. U.S. Gov. Ptg. Office, Washington, D.C., 1969.
4. Sopher, I.M. and Masemore, W.C. The investigation of vehicular carbon monoxide fatalities. Traffic Digest and Review 1-11, Nov. 1970.
5. Gettler, A.O. and Freimuth, H.C. Carbon monoxide in blood: A simple and rapid estimation. Amer. J. Clin. Path. 13:79-82, 1943.
6. Finck, P.A. Exposure to carbon monoxide: Review of the literature and 567 autopsies. Military Med. 131:1513-1539, 1966.
7. Bucic, M.; Prohic, H.; and Moljevic, O. [Multiple accidental carbon monoxide poisoning during sex relations in a parked car in a garage.] Medicinski Arhiv. 23:69-74, Jul.-Dec., 1969.
8. Mallach, H.J. and Röseler, P. Beobachtungen und Untersuchungen über die gemeinsame Wirkung von Alkohol und Kohlenmonoxyd. Arzneimittel-Forschung 11:1004-1008, 1961.
9. Waller, J.A. and Thomas, K. Smoking and fatal highway crashes. Read before the American Association for Automotive Medicine, Colorado Springs, 1971.
10. Haddon, W., Jr. On the escape of tigers: An ecologic note. AJPH 60:2229-2234, 1970.
11. Booz-Allen Applied Research Inc: Vehicle-in-use system safety analysis. Volume IV: Safety analysis of visibility and human impairment. Report to U.S. Dept. of Transportation, Contract #FH-11-7316, 1970.
12. Periodic Motor Vehicle Inspection: A Comparative Data Analysis. American Association of Motor Vehicle Administrators, Washington, D.C., 1971.
13. Norman, J.N. and Ledingham, I.McA. Carbon monoxide poisoning: Investigations and treatment. Progr. Brain Res. 24:101-122, 1967.
14. Pearce, J. Hyperbaric oxygen in carbon monoxide poisoning. Brit. Med. J. 2:53, 1969.
15. Winter, A. and Shatin, L. Hyperbaric oxygen in reversing carbon monoxide coma. New York State J. Med. 70:880-4, 1970.
16. Norman, J.N.; MacIntyre, J.; and Shearer, J.R., et al. Use of a one-man, mobile pressure chamber in the treatment of carbon monoxide poisoning. Brit. Med. J. 2:333-334, 1970.
17. Smith, J.S. and Brandon, S. Acute carbon monoxide poisoning - 3 years experience in a defined population. Postgraduate Med. J. 46:65-70, 1970.
18. Sunshine, I.; Hodnett, N.; and Hall, C.R., et al. Drugs and carbon monoxide in fatal accidents. Postgraduate Med. 43:152-155, 1968.
19. Baker, S.P. Characteristics of Fatally Injured Drivers: Report to U.S. Dept. of Transportation, Contract #FH-11-7092, 1970.

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